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Solar Magnetic Fields and Spacecraft Observations

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The observations of the solar magnetic fields discussed earlier in this meeting were all made in, or near, the photosphere. However, it is the fields at higher elevations, in the chromosphere and corona, that are directly involved in flares. And it is the fields above the flares that govern the escape of energetic particles from the sun and are so important in influencing the radio noise emitted in conjunction with flares. Unfortunately, no direct observations of these magnetic fields have been made and we must seize upon any indirect clues available. Thus, although the observations made by Mariner II between the orbits of earth and Venus have much less bearing on fields in flares than do observations in the photosphere, I do feel that this source of information should not be disregarded completely. It does tell us a good deal about the outer boundary conditions for the solar corona at one stage of the solar cycle, and we cannot understand the corona, or phenomena that occur within it, unless we take account of these boundary conditions.

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12

In my own view, the most important observation made by Mariner II was the confirmation by Snyder and Neugebauer that, at this phase of the solar cycle at least, the solar wind blows all the time with a velocity that is usually between 350 and 750 km/sec. It is a universal phenomena, not merely an intermittent product of disturbances.

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I wish to describe a tentative model that may explain several features of the Mariner II observations of the solar wind. It will be very surprising if this model turns out to be really correct, but it is the best that I can suggest now and I hope that consideration of it will guide us to the correct model.

Near the orbit of the earth, the momentum flux of the solar wind is so much greater than the magnetic stresses that the wind dominates the field, blowing where it will and sweeping any field imbedded in it along. But as one goes in toward the sun, it is easily seen that the magnetic stresses grow more rapidly than does the momentum flux. Somewhere within about 10 or 20 solar radii the magnetic field comes to dominate the situation. In the lower corona, the gas can not rise up uniformly to provide the source of the solar wind. Over most of the surface of the sun the gas must be partially held down by being confined within tubes of force both of whose ends are attached to the sun. Only where the field is relatively regular, fairly weak, and nearly vertical can the gas rise up easily to higher elevations and eventually pull the field lines out. Thus it appears that as the solar wind carries away the outer corona, the gas which replenishes it may well up from the photosphere over only a few areas and may spread out at higher elevations to fill the upper corona. It would then follow that the magnetic field in the outer corona, which is swept out to interstellar space by the solar wind, would all come up through the photosphere in these few areas. The radial component of the solar magnetic field in the solar wind should remain of the same sign over much larger areas of the sun than does the field observed in the photosphere. This model was originally suggested by the Mariner II magnetometer observations, which give some support for this feature of the coronal field. However, alternative interpretations are possible that do not require it.

At intermediate distances from the sun, the magnetic fields and the momentum of the gas become of comparable importance in determining the motion. The gas sweeps the field lines but they are still able to influence the gas motions. In this region the tubes of force should resemble nozzles that direct the gas flow. The gas flow in such a nozzle is affected both by its shape and, on Parker's theory of the solar wind, by the temperature distribution along its axis. The temperature distribution is presumably determined by adiabatic expansion, by energy derived from damped waves, and by thermal conductivity which should be mainly along the field lines. Since the temperature distribution resulting from conductivity will be a function of the dependence of the cross section of the tube of force on distance from the sun, nozzles of different shapes should produce solar wind streams of different velocities and densities. Thus the high velocity streams which Snyder and Neugebauer find recurring at 27-day intervals over the same area of the sun may be due to a persistence in the magnetic field configuration. The relatively narrow angular width of these streams seems to require ejection from some kind of nozzle rather than an origin in a local hot spot from which the gas would stream forth in a wide cone with both high velocity and high density.

Finally, this model may provide an explanation of the fact that there is a delay of only about a day between the central meridian passage of a plage region and arrival at the earth of the high velocity jet of solar wind that Dr. Snyder associated with it. From the velocity alone one would expect a delay of more than two days. As Dr. Snyder pointed out in his paper yesterday, corotation out to about 1/2 A.U. would explain the effect. Indeed, if one allows for the facts that disturbances should propagate outward with the sum of the wind and hydromagnetic wave velocities and that even beyond the point where there is corotation there is some further motion in longitude because the wind tends to conserve angular momentum, one finds that corotation is necessary out to only about 1/4 A.U. I believe that corotation is unlikely to extend this far out. However if the lines of force are systematically inclined forward near the sun, rather than backward as one might at first expect, it becomes very easy to explain the short delay. An investigation, still in its preliminary stages, of the interaction between the field swept out by the wind and the rotation of the wind about the sun gives some support for the possibility that the lines may be inclined forward. Alternatively, it could be argued that the high velocity gas comes systematically from the leading part of the plage area.

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